SECTION 1

INTRODUCTION

1.1 This manual was prepared to assist biologists and managers in USEPA and other Federal, state, and private water monitoring organizations in the use of fish as indicators of ecosystem health and for evaluating the biological integrity of surface waters and protecting quality water resources. The manual contains biological criteria and laboratory and field methods that will aid in the monitoring and bioassessment of the effects of anthropogenic and environmental stresses on fish populations and communities. It will also facilitate the expansion and refinement of our knowledge of the ecological requirements of fish species in freshwater, estuarine, and marine habitats.

1.2 The manual includes sections on quality assurance and quality control, safety and health, sampling methods and techniques, sample preservation and identification, data analyses, special techniques, bioassessment protocols for use in streams and rivers, a family-level ichthyoplankton index method, fish health and condition assessment procedures, guidelines for fish sampling and tissue preparation for bioaccumulative contaminants, and a fisheries bibliography. Guidelines and procedures for fish kill investigations are provided.

1.3 Fish community evaluation and assessment should measure the overall structure (number of species and individuals within a community) and function (organism interaction in the utilization of food and other biological resources) of various aquatic habitats considered for study. These measurements should include such factors as habitat characteristics and quality, riparian vegetation, and hydraulic characteristics that are expected to influence fish community spatial and temporal variability. One must also distinguish the alterations induced by anthropogenic activities from natural variations which occur in the environment.

1.4 In North America, fish are the focus of economically important sport and commercial fisheries, and are an important source of food for humans. To the general public the size and species composition of a fish community is the most meaningful index of pollution.

1.5 In most aquatic ecosystems, fish are usually the most common vertebrates. Fish communities occupy the upper trophic levels of aquatic food webs, and they are dependent on the same or other trophic level life forms for food. In aquatic communities fish can be one of the most sensitive indicators of water quality assessment and biological integrity in aquatic environments (Angermeier et al., 1991; Fausch et al., 1990; Karr, 1981, 1987, 1990, 1991; Smith, 1971; McKenzie et al., 1992). The literature contains much data on fish species distribution, life histories, ecology, pollution tolerance, and environmental requirements. Fish are directly and indirectly affected by chemical and physical changes in the environment, and the population or community of fish in rivers, streams, lakes, estuaries, and oceans reflects the state of the health of the aquatic environment or watershed as a whole.

Because they are conspicuous, fish populations or fish assemblages are commonly used as environmental indicators or as an index for water quality (Table 1).

1.6 Water quality conditions that significantly affect the lower levels of food webs (e.g., plankton and benthic invertebrates, including macroinvertebrates, USEPA, 1990a) will affect the abundance and species composition of the fish population. In some cases, fish may exhibit signs of being more sensitive to certain pollutants than are the lower animals and plants, and may be adversely affected even when the lower levels of food webs are relatively unharmed.

1.7 Karr (1981, 1987), Karr et al. (1986, 1987), Ohio EPA (1990), and USEPA (1990a,b) have indicated that five major sets of abiotic and biotic factors affect and ascertain biological integrity or water resource integrity (Table 2). To determine anthropogenic or natural impact on aquatic ecosystems, all monitoring or bioassessment programs must survey and evaluate in a methodical and systematic way all five sets of factors. Although a thorough discussion of all these factors is beyond the scope of this document, a discussion of how some of these factors influence the biological integrity of surface waters and several methods and procedures in evaluating these complex set of factors are presented here. For a more comprehensive discussion of all these factors, consult USEPA (1990a, 1990b), Ohio EPA (1990), and the references in Section 12, Fisheries Bibliography.

1.8 Many species of fish have stringent dissolved oxygen and temperature requirements and are intolerant to chemical and physical contaminants resulting from municipal, agricultural, industrial, forestry, and mining activities. Also, fish communities are sensitive to and good indicators of macrohabitat disturbances (Rankin, 1989).

1.9 The discharge of moderate amounts of degradable organic wastes may increase the nutrient levels (eutrophication) in the habitat and result in an increase in the standing crop (total amount of the biomass of organisms of one or more species within a locality) of fish. This increase usually occurs in one or a few species and results in an imbalance in the population. The discharge of large amounts of degradable organic materials may result in depressed oxygen levels which may reduce the number and kinds of fishes present and increase the standing crop of pollution tolerant species. In extreme cases the fishery may be eliminated in the affected area.

1.10 The effects of toxic wastes may range from the elimination of most fish to a reduction in reproductive capacity (fecundity) or resistance to disease and parasitism. Massive and complete fish kills are dramatic signs of abrupt, adverse changes in environmental conditions. Fish, however, can repopulate an area rapidly if the habitat is not destroyed and the water quality improves. The cause of the fish kill may be difficult to detect by examination of the fish community after it has recovered from the effects of the pollutant. Chronic pollution, on the other hand, is more selective in its effects, exerts its influence over a long period of time, and causes recognizable changes in the species composition and relative abundance of the fish.

TABLE 1. ATTRIBUTES OF FISHES AND DESIRABLE COMPONENTS FOR BIOASSESSMENT AND BIOMONITORING PROGRAMS[1]

Goal/Quality	Attribute
Accurate Assessment of Aquatic Ecosystem Integrity	Fish populations and individuals generally remain in the same area during summer seasons.
	Communities are persistent and usually recover rapidly from natural disturbances. Comparable results can be expected from an unperturbed site at various times within a season.
	Fish have larger home ranges and are less affected by natural microhabitat differences than smaller organisms, such as macroinvertebrates. This makes fish extremely useful for assessing regional, macrohabitat, and mesohabitat differences.
	Most fish species have long life spans (3-10+ years) and can reflect both long term and current water resource quality.
	Fish continually inhabit the receiving water and reflect the chemical, physical, and biological histories of the water.
	Fish represent a broad spectrum of community tolerances from very sensitive to highly tolerant, and respond to chemical, physical, and biological degradation in characteristics response patterns.
Visibility	Fish are a highly visible component of the aquatic community, and so are of interest to the public.
	Aquatic resource uses and regulatory language are generally characterized in terms of fish (i.e., fishable and swimmable goals of the Clean Water Act).
Ease of Use and Interpretation	The sampling frequency for trend assessment is less than for short-lived organisms.
	The taxonomy of fishes is well established, allowing professional biologists the ability to reduce laboratory time by identifying many specimens in the field.
	The distribution, life histories, and tolerances to environmental stresses of most North American species are well documented in the literature.

[1]Adapted from Simon (1991).

TABLE 2. FIVE MAJOR CLASSES OF ENVIRONMENTAL FACTORS WHICH INFLUENCE AND DETERMINE THE BIOLOGICAL INTEGRITY OF SURFACE WATERS WITH SOME OF THEIR IMPORTANT CHEMICAL, PHYSICAL, AND BIOLOGICAL COMPONENTS IN LENTIC AND LOTIC SYSTEMS[1]

STREAMS, RIVERS	LAKES, RESERVOIRS, ESTUARIES, OCEANS
1. ENERGY SOURCE	
Nutrient cycling	Nutrients cycling
Organic matter particle size	Organic matter particle size
Primary productivity	Primary productivity
Seasonal cycles	Seasonal cycles
Solar radiation	Solar radiation
2. WATER QUALITY/CHEMICAL VARIABLES	
Adsorption	Adsorption
Alkalinity	Alkalinity
DO	DO
Hardness	Hardness
Metals, other toxic substances	Metals, other toxic substances
Nutrients	Nutrients
Organics	Organics
pH	pH
Solubility	Solubility
Temperature	Temperature
Turbidity	Turbidity
Water cycling	Water cycling
3. HABITAT QUALITY	
Bank stability	Bank stability
Canopy	Shoreline vegetation
Channel morphology (riffles, pools)	Substrate types
Current velocity	Siltation
Gradient	Wave action
Instream cover (woody debris)	Width/depth
Riparian vegetation	Inwater abiotic/biotic cover
Siltation	
Sinuosity	
Substrate types	
Width/depth	

[1]Adapted from Karr (1987, 1991), Karr and Dudley (1981), Karr et al. (1986, 1987), and USEPA (1990a; 1990b).

TABLE 2. FIVE MAJOR CLASSES OF ENVIRONMENTAL FACTORS WHICH INFLUENCE AND DETERMINE THE BIOLOGICAL INTEGRITY OF SURFACE WATERS WITH SOME OF THEIR IMPORTANT CHEMICAL, PHYSICAL, AND BIOLOGICAL COMPONENTS IN LENTIC AND LOTIC SYSTEMS (CONTINUED)

4. FLOW REGIME

STREAMS, RIVERS	LAKES, RESERVOIRS, ESTUARIES, OCEANS
Ground water	Ground water
High/low extremes	High/low extremes
Land use	Land use
Precipitation/runoff	Precipitation/runoff
Water volume	Water volume

5. BIOTIC ASSOCIATIONS

STREAMS, RIVERS	LAKES, RESERVOIRS, ESTUARIES, OCEANS
Feeding	Feeding
Competition	Competition
Disease	Disease
Parasitism	Parasitism
Predation	Predation
Reproduction	Reproduction

1.11 The utilization of biological components (structural and functional) to evaluate the ambient aquatic community of our nations surface water has been discussed and well documented in the literature. Some recent examples are Crowder (1990), Downing et al. (1990), Fausch et al. (1990), Hunsaker and Carpenter (1990), Karr et al. (1986), Karr, (1991), Ohio EPA (1987a, 1987b, 1989, 1990), Plafkin et al. (1989), Shuter (1990), Simon (1991), and USEPA (1990a, 1990b). Structural components of fish communities include diversity, taxa guilds, numbers, and biomass. Functional components of fish communities include the feeding or trophic strategy, reproductive behavior and guild classification, and environmental tolerance to perturbations.

1.12 The principal characteristics of interest in bioassessment studies of fish populations include: (1) species richness (number of species)--presence or absence; relative and absolute abundance of each species, (2) size distribution, (3) habitat guilds--pelagic, littoral, and benthic species, (4) trophic guilds--omnivores, piscivores, and invertivores, (5) growth rate, (6) condition factor, (7) reproductive guilds, egg production and success, (8) general tolerance guilds (indicator taxa)--intolerant, tolerant, and sensitive species, (9) incidence of disease and parasitism (10) fish kills, (11) palatability, and (11) fishability--catchability, desirability, and sustainability. Observations of fish behavior can also be valuable in detecting environmental problems, e.g., ventilation rates, position in the current, and erratic movement. Fish may also be utilized for field and laboratory bioassays (USEPA, 1991a, 1991b, 1992a, 1992b), for tissue analyses to measure the concentrations of metals and pesticides (see Section 10, Guidelines for Fish Sampling and Tissue Preparation for bioaccumulative Contaminants) for histopathologic examination (Hinton and Lauren, 1990), and biomarker studies (Adams, 1990a, 1990b; Anderson, 1990; Jimenez and Stegeman, 1990; Rice, 1990; Schreck, 1990; and Thomas, 1990).

1.13 Fisheries data are useful in enforcement cases and in long-term water quality status and trends monitoring (Tebo, 1965; Ohio EPA, 1990; USEPA, 1991a). Before fishery surveys are initiated, a careful and exhaustive search should be conducted for existing information on the fish populations or communities in question. State and Federal fishery agencies and universities may be potential sources of information. If data are not available and a field study must be conducted, State and other Federal agencies may assist in a survey and may provide needed expertise and specialized equipment for the collection of specific, local fishes. A joint effort is usually more economical and efficient and will promote continued cooperation between agencies and parties involved.

1.14 Fisheries data may have limitations. Even if the species composition of the fish in a specific area is known before and after the discharge of pollutants, the significance of changes in the catch might not be satisfactorily interpreted unless there are adequate data on spawning, seasonal migration, temperature requirements and stream-flow responses, feeding activities, diurnal movements, habitat preferences, and activity patterns. Without adequate data, fish presence or absence cannot be directly correlated with water quality. Furthermore, any existing data of known quality on the water quality requirements of fish would be of value in interpreting field data.

1.15 Federal and state regulations usually require a fish collecting permit because some species of fish are protected by law, and the collection of others is regulated. The state fishery agencies must be contacted before fish can be taken in a field study. Investigators should confirm that they have complied with federal and state regulations before collecting samples of fish. The state should be contacted prior to any fish study to ensure that investigators comply with current regulations.

1.16 The design of fish studies should be based upon study goals and data quality objectives (DQOs) (see Section 2, Quality Assurance and Quality Control). To supplement the material contained in this manual, a number of basic references should be reviewed by investigators involved in fish sampling programs and studies. Useful references include Adams (1990), Angermeier et al. (1991), APHA (1992), Bartell (1990), Edwards and Megrey (1989), Evans et al. (1990), Everhart and Youngs (1981), Fausch et al. (1990), Gammon (1980), Gammon et al. (1990), Hankin and Reeves (1988), Hellawell (1986), Herricks and Schaeffer (1985), Hirsch et al. (1988), Hughes et al. (1986), Johnson and Nielsen (1983), Karr (1981, 1987, 1990, 1991), Karr and Dionne, 1991, Karr and Dudley (1981), Karr et al. (1983, 1986, 1987), Magnuson (1991), Manci (1989), Mangel and Smith (1990), Minshall et al. (1989), Ohio EPA (1986, 1987a, 1987b, 1989, 1990), Omernik (1987), Platts et al. (1983), Robins et al. (1991), Schreck and Moyle (1990), Templeton (1984), Tonn (1990), USEPA (1988), USEPA (1990a, 1990b), (USEPA, 1991c, 1991d, 1991e), Whittier and Paulsen (1992), Wooten (1990), and Yoder (1991).

1.16.1 If fish data are to be useful, they must be acquired according to standardized sampling methods and analyzed with appropriate statistical methods. Two very important qualities of sampling data are accuracy and precision. Accuracy refers to how well the sample represents the whole of the study. In fishery studies, collecting accurate (or unbiased) data may be difficult because studies are poorly designed. Precision refers to repeatability of data. To supplement the statistics in this document, investigators should consult the commonly cited statistical references (Cochran, 1977; Conover, 1980; Green, 1979; Hicks, 1982; Snedecor and Cochran, 1981; Sokal and Rohlf, 1981; Zar, 1984).

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